Use of Multi-Criteria Decision Making in Establishment of Solar Power Plant in NIT Rourkela

A Project Report Submitted in Fulfilment of the Requirements for the Degree of

B. Tech.

(Mechanical Engineering)

By

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Certificate of Approval

This is to certify that the thesis entitled Multi-Criteria Decision Making in Establishment of Solar Power Plant in NIT Rourkela by AHP submitted by Malay Milan Choudhury has been carried out under my supervision in partial fulfilment of the requirements for the Degree of Bachelor of Technology (B. Tech.) in Mechanical Engineering at National Institute of Technology, Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abstract

In majority of decision-making processes it is imperative that one considers several conflicting targets. The term "Multiple Criteria Decision Making (MCDM)" describes several ways developed specifically to aid decision makers in reaching the most optimized decisions. Sustainable Energy planning problems are complex problems with multiple decision makers and a multitude of criteria. That is why, such problems are very much suited to the use of MCDM. A multitude of MCDM methods exists. Each of the methods to be used such as ELECTREE, AHP, VIKOR, TOPSIS, and ANP etc. has its advantages and drawbacks. Methods from all of these groups have been applied to sustainable energy related decision making problems, especially in the mathematical assessment of alternative electricity supply strategies, which in our case is planning an optimized strategy for the proposed solar power plant in NIT Rourkela using Analytical Hierarchy Process (AHP). Till date, studies of Multi-Criteria Decision Making in energy planning have most often considered energy networks with only one energy carrier. More developed energy systems with various energy suppliers have not been given proper importance, although this field is supposed to be suitable for use of MCDM due to its deep complexity, plenty of decision-makers and several conflicting criteria.

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Chapter 1

Introduction

The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making approach and was presented by Saaty (1977 and 1994). The AHP has pulled in light of a valid concern for many a scientist for the most problems because of its efficient and fine scientific properties of the strategy and the way that the requisite data information are simple to get. The AHP is a decision-making facilitation tool, which can be utilized to tackle complex decision-making issues. It makes use of a multi-layer consecutive structure of goals, criteria as well as sub-criteria, and choices. The appropriate information is inferred by utilizing an arrangement of pairwise correlations. These pairwise comparisons are utilized to get the weights of the significance of the decision criteria and the relative execution measures of the options regarding every individual decision-making criterion. Considering the chance that the correlations are not consummately steady, then it gives a system to enhancing consistency.

The AHP gives an advantageous way to deal with taking care of complex MCDM issues in designing. It ought to be noticed that there is a product bundle, called Expert Choice (1990), which was particularly added to the broad acknowledgement of the AHP system. Be that as it may, as this paper showed with some illustrative illustrations, its utilization to building issues should be a mindful one. There is adequate confirmation to propose that the proposals made the AHP ought not to be taken truly. In matter of actuality, the closer the last need qualities are with one another, the less rushed the client ought to be.

Chapter 2

Literature Review

Energy is the essential prerequisite for a comprehensive national development. Constantly a big portion of Indian economy – farming, industry, transport, business, and local – demands a continuous power supply. All the projects for per-capita development that are executed since independence have essentially obliged expanding measures of power generation. Subsequently, utilization of available energy in all structures has been consistently rising everywhere throughout the nation. This expanding need of electricity power has brought on in the nation getting to be generally more reliant on fossil powers, for example, thermal power plants, oil based power and natural gas mostly imported or mined from Krishna Godaveri Basin (KGB). Skyrocketing costs of petroleum oil & gaseous fuels and consequent possible lack of the same to our posterity leads us towards an uncertainty in our energy security and worldwide financial improvement. Expanded utilization of fossil fills likewise causes ecological issues both generally and all around. Against this foundation, the nation critically needs to build up a sustainable way of energy growth. Growth in energy security and widespread utilization of renewable energy sources are two faces of the same coin which in other words is also called a manageable power supplement. Fortunately, ours is one such country with plenty of energy sources which are non-conventional in nature; the most foundational ones are biomass based, biogas based, solar, wind mill based, and some amount of hydro power nevertheless. (Substantial hydro force is additionally which are by nature renewable, however it's been in use everywhere throughout the earth surface for a long time, yet it is for the most part excluded in the terms of 'non-conventional and renewable energy sources.) Advanced municipalities and tech squanders are likely be termed as helpful sources of energy, however they are fundamentally distinctive types of biomass.

Renewable sources of energy have some of the following features;

- Uninterrupted supply
- Local availability and no need of arrangement of any transport facility
- No matter how small the facility is, it is economical.
- Environment-friendly
- Totally suitable for domestic as well as small scale decentralized usage.

The Government of India’s Ministry for Non-Renewable Energy Sources has always been in the process of actualizing exhaustive projects to improve the tapping of various available renewable energy sources in the nation. The result of endeavours devoted to this field in particular, amid the last half century, various advancements and gadgets have been produced and have ended up economically viable. Such ventures are some of the following; biogas plants, customized wooden stove, solar powered water heater/purifiers, solar powered cookers and solar lights, lighting system in the streets, wind based electric generators, wind based water pumps - especially water-pumping wind factories, biomass fuelled gasifiers, & Solarification of NIT Rourkela for the fact. Energy innovations strategies for the future, for example, hydrogen, power devices, and bio-powers are in use today are effectively created. India is undertaking one of the biggest projects in renewable energy in the whole world. The nation positions itself as second on the planet in biogas use and ranks the 5^{th} in wind power and photo-voltaic creation. Renewable sources as of now add to around 5% of the aggregate force creating limit in the nation.

The advantages of setting up a campus-based solar power plant are:

• Completely independent from hydro or thermal powered energy: The prices of such type of energy will rise in near future as a result of a curtailed supply, which makes the same unaffordable.

• Entirely pollution free form of production. It’s green.

• Solar power can be used anywhere, but again, energy obtained both from power plants and the windmill is not accessible in many areas due to lack of resources.

• The life expectancy of the solar equipment is very long lasting, however, the ones required for hydro power plants or wind mills require more technically advanced equipment and need alternatives more often too.

• Solar energy can give a reliable output majority of the time while this cannot be assured in the case of wind and hydro-electric energy. Power output in the later cases may be erratic/inconsistent in certain areas.

• Solar equipment is essentially simple and can be very smoothly installed. Such establishments may also be maintained for long span without the need of being monitored. On another side, equipment, parts and spares necessary for hydro-electric and wind power plant would need proper control system and a great deal of expertise to install them properly.

One of the successful campus solar power plant project has been implemented at IIT Roorkee as shown in Figure 1.

Figure 1: India's largest campus-based solar power plant at IIT Roorkee (1.8MW)
(Source: http://www.tatapowersolar.com/images/slider/20140416144446.jpg)

Solar photovoltaic systems for generating electricity need a high initial investment but (more importantly) they have very low or negligible running cost. A solar module has a life of around 25 years and delivers reliable performance throughout its life. Alternatives such as Diesel Generators that are dependent on a regular supply of fuel with maintenance, transportation , cost of replacement, noise & smoke pollution, one can understand the 'total life cycle cost' of a system and thereby the cost advantage of solar systems.

Chapter 3

AHP Methodology and Application

Analytical Hierarchy Process (AHP) has essentially been a vital part of the science of Multi-Criteria Decision Making (MCDM). Although it is one of the most basic methods for decision-making, it has inspired the development of many more methods for easier and more effective calculations. However, AHP has been at the centre of so many controversies; reasons being either theoretical and practical. In the early days, it was observed that AHP can negate out an alternative if an equally important option is already available without considering its other properties. So came the "Revised AHP”. There exists another variant of AHP; “Ideal Mode AHP". Nevertheless, AHP, in today's world considered one of the most effective tools of decision modelling and vital constituent of MCDM.

Pair-wise Comparisons are one kind of the most prominent techniques used in many a method of MCDM. This technique is not limited to just AHP, rather it has been an integral part of many other methods as it furnishes the quantitative data to the observer and paves the way for a smoother calculation. The link between quantitative data and absolute values is established by AHP. For example “What is the quantitative priority of a MATLAB programme in terms of short-range output declaration as compared to another of the same kind?" In such cases, it gets very difficult to establish a correct relation and thus make the accurate decision. Here comes the relevance of pair-wise comparison which has been an epicentre of interest of many scientists. Pair-wise comparisons are made to determine the relative importance of one event (alternative) in terms of another with the same criterion in the hind sight. In other words it gives us the relative importance of one against another. Table 1 shows a rough example of how pairwise calculation tables are constructed. It gives mathematical definition to otherwise linguistic terms such as “A is relatively more favourable than B.”

Table 1: Formation of a pairwise comparison matrix

Available Alternatives	A	B	C
A	1	p	q
B	1/p	1	r
C	1/q	1/r	1

Scales are used to quantify pairwise comparisons. Such scales (total 78 of them available) are a system platform for comparison between linguistic attributes and mathematical weight. They are given discrete numbers which represent their relative weights. But there is a huge drawback in this process, which is sometimes people cannot judge a relative comparison between 3 to 3.02 times stronger/weaker priority between two alternatives. There Saaty established this specific 9 set scale, as shown in Table 2 below.

Table 2: Saaty's priority table and its significance

Extent of Importance	**Definition**	**Explanation**
1	Equal Importance	Both the event have equal contribution towards the objective
3	Mild importance of one event over another	Inference slightly prefers one with higher bias
5	Considerable importance of one over another	Judgement necessarily favours one event
7	Apparent relative importance	One event is highly favoured over the other. In this case, the other one is usually ignored.
9	Absolute importance	The inferior event is eliminated out
2,4,6 and 8	Compromise values	When we need to adjust values so as to make it consistent

To ascertain the correctness of the comparison matrices, it is equally necessary that we find the right Eigen Vector. From the judgement matrix, the geometric mean of row and column averages are calculated with necessary steps as shown in the observations is how Eigenvector is calculated. RI values for different values of criteria (n) is given in Table 3.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Table 3: Random inconsistency values for different number of criteria

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Chapter 4

Problem Specification and Procedure

The project needed to make six particular decisions pertaining to the proposed solar power plant in the campus. They are; the choice of the inverter, batteries, grid technology, selection of solar module, selection of the most appropriate location for the plant and the grid size to be set up.

In the case of the inverter, it was necessary to make a pairwise comparison between the three available alternatives on the basis of 3 criteria; peak surge, output voltage and efficiency.

The first matrix in every specific calculation is a pairwise comparison matrix between the available alternatives. The next matrix in the calculation set is a normalized matrix. It is obtained by dividing the matrix elements of the pairwise comparison matrix by their respective column sum. It is usually denoted in terms if decimals.

The weight matrix was calculated by taking the row averages of the elements of the normalized matrix. If the weight matrix is identical to all the columns of the normalized matrix, the comparison matrix is consistent and the relative importance if the alternatives are same as the respective elements of the weight matrix. If the weight matrix is not identical with the columns of the normalized matrix, CR (Consistency Ratio) is needed to be calculated, the procedure of which is explained in the section AHP methodology. If the CR values come less than or equal to 0.1, one is expected to assume the pairwise comparison to be consistent and take the values of the weight matrix as the priority order of the alternatives.

Selection of Inverter according to Peak Surge

The three available alternatives for the inverter as compared on the basis of peak surge first and then output voltage and efficiency consecutively. The first matrix shows the pairwise comparison between the SSS, AI and DI type inverters on the basis of peak surge.

$$\begin{array}{c} \\ \text{SSS} \\ \text{AI} \\ \text{DI} \end{array} \begin{array}{c} \begin{array}{ccc} \text{SSS} & \text{AI} & \text{DI} \end{array} \\ \begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 3/2 \\ 1/3 & 2/3 & 1 \end{bmatrix} \end{array}$$

Normalized matrix was found as follows:

$$\begin{array}{c} \\ \text{SSS} \\ \text{AI} \\ \text{DI} \end{array} \begin{array}{c} \begin{array}{ccc} \text{SSS} & \text{AI} & \text{DI} \end{array} \\ \begin{bmatrix} 0.545 & 0.545 & 0.545 \\ 0.273 & 0.273 & 0.273 \\ 0.182 & 0.182 & 0.182 \end{bmatrix} \end{array}$$

Weight Matrix was calculated as follows:

$$\begin{bmatrix} 0.545 \\ 0.273 \\ 0.182 \end{bmatrix}$$

The comparison is consistent because the weight matrix is identical with the columns of the normalized matrix.

Selection of Inverter according to Output voltage

In the following calculation, inverters were judged on the basis of their respective output voltage.

$$\begin{array}{c|ccc} & SSS & AI & DI \\ \hline SSS & \multicolumn{3}{c}{\multirow{3}{*}{}} \\ AI & & & \\ DI & & & \end{array}$$

$$\begin{array}{c} SSS \\ AI \\ DI \end{array} \begin{bmatrix} 1 & 1/2 & 1/5 \\ 2 & 1 & 1/2 \\ 5 & 2 & 1 \end{bmatrix}$$

Normalized Matrix for the above matrix was found to be as follows:

$$\begin{array}{c} \\ SSS \\ AI \\ DI \end{array} \begin{array}{c} \begin{array}{ccc} SSS & AI & DI \end{array} \\ \begin{bmatrix} 0.125 & 0.143 & 0.118 \\ 0.250 & 0.286 & 0.294 \\ 0.625 & 0.571 & 0.588 \end{bmatrix} \end{array}$$

Weight Matrix was calculated as:

$$\begin{bmatrix} 0.129 \\ 0.277 \\ 0.594 \end{bmatrix}$$

Product Matrix was found as:

$$\begin{bmatrix} 0.3863 \\ 0.8320 \\ 1.7930 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.0113

CI= 0.00565

RI= 0.66

CR= CI/RI = 0.00856 (Consistent)

Selection of Inverter according to Efficiency

Inviters according to their efficiency were prioritized here, proceeding in the same manner as the previous one:

$$\begin{array}{c|c} & \begin{array}{ccc} \text{SSS} & \text{AI} & \text{DI} \end{array} \\ \hline \begin{array}{c} \text{SSS} \\ \text{AI} \\ \text{DI} \end{array} & \begin{bmatrix} 1 & 1 & 7 \\ 1 & 1 & 3 \\ 0.14 & 0.3 & 1 \end{bmatrix} \end{array}$$

Normalized Matrix was calculated as this:

$$\begin{array}{c|c} & \begin{array}{ccc} \text{SSS} & \text{AI} & \text{DI} \end{array} \\ \hline \begin{array}{c} \text{SSS} \\ \text{AI} \\ \text{DI} \end{array} & \begin{bmatrix} 0.476 & 0.429 & 0.63 \\ 0.467 & 0.429 & 0.27 \\ 0.065 & 0.128 & 1 \end{bmatrix} \end{array}$$

Weight Matrix was as follows

$$\begin{bmatrix} 0.51 \\ 0.39 \\ 0.10 \end{bmatrix}$$

Product Matrix was calculated as:

$$\begin{bmatrix} 1.6 \\ 1.2 \\ 0.2884 \end{bmatrix}$$

Consistency Calculation

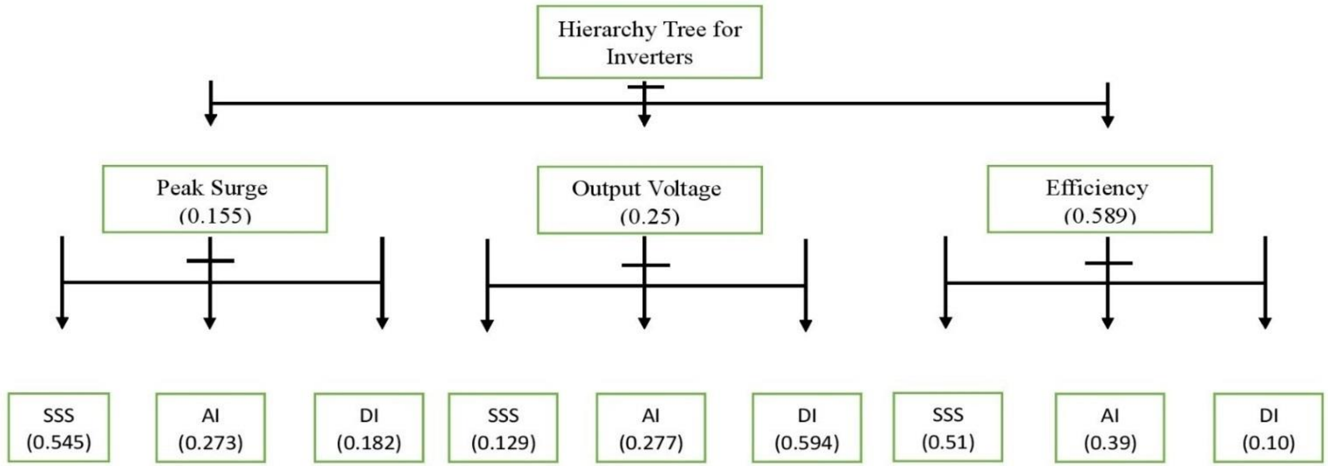
n_{max} = 3.0884

CI= 0.0442

RI= 0.66

CR= CI/RI = 0.10 (Consistent)

The result for the best alternative of inverters to be used has been specified in Figure 2.



<u>Choice of SSS</u>

0.155*0.545
+ 0.25*0.129
+ 0.589*0.51
= **<u>0.417</u>**

<u>Choice of AI</u>

0.155*0.273
+ 0.25*0.277
+ 0.589*0.39
= 0.341

<u>Choice of DI</u>

0.155*0.182
+ 0.25*0.594
+ 0.589*0.10
= 0.235

Figure 2. Hierarchy Tree for selection of Inverters

Selection of Batteries according to Cost and Maintenance

The three available alternatives for the batteries are compared on the basis of cost and maintenance first and then life expectancy and efficiency respectively. The first matrix shows the pairwise comparison between the Lead-Acid, Ni-Cd and Li-ion type inverters on the basis of cost and maintenance.

$$\begin{array}{c|ccc} & \text{Lead-Acid} & \text{Ni-Cd} & \text{Li-ion} \\ \hline \begin{array}{c}\text{Lead –Acid}\\ \text{Ni-Cd}\\ \text{Li-ion}\end{array} & \multicolumn{3}{c}{\begin{bmatrix} 1 & 0.50 & 3 \\ 2 & 1 & 4.0 \\ 0.45 & 0.25 & 1 \end{bmatrix}} \end{array}$$

Normalized Matrix was assimilated to be as this:

$$\begin{array}{c|ccc} & \text{Lead-Acid} & \text{Ni-Cd} & \text{Li-ion} \\ \hline \begin{array}{c}\text{Lead – Acid}\\ \text{Ni-Cd}\\ \text{Li-ion}\end{array} & \multicolumn{3}{c}{\begin{bmatrix} 0.2899 & 0.2857 & 0.3750 \\ 0.5797 & 0.5717 & 0.5000 \\ 0.1304 & 0.1429 & 0.1250 \end{bmatrix}} \end{array}$$

Weight Matrix for the above calculation was calculated as:

$$\begin{bmatrix} 0.3169 \\ 0.5504 \\ 0.1328 \end{bmatrix}$$

Product Matrix as also calculated similarly.

$$\begin{bmatrix} 0.990338 \\ 1.715148 \\ 0.412948 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.118434

CI= 0.058696

RI= 0.66

CR= CI/RI = 0.10 (Consistent)

Selection of Batteries according to Life Expectancy

In the following calculations, batteries are weighed on the criterion of life expectancy proceeding from the previous in a similar fashion.

$$\begin{array}{c|ccc} & \text{Lead-Acid} & \text{Ni-Cd} & \text{Li-ion} \\ \hline \text{Lead-Acid} & & & \\ \text{Ni-Cd} & & & \\ \text{Li-ion} & & & \end{array} \quad \begin{bmatrix} 1 & 1/3 & 3.50 \\ 2 & 1 & 2 \\ 1/4 & 1/2 & 1 \end{bmatrix}$$

Normalized Matrix was found to be as follows:

$$\begin{array}{c} \\ \text{Lead-Acid} \\ \text{Ni-Cd} \\ \text{Li-ion} \end{array} \begin{array}{ccc} \text{Lead-Acid} & \text{Ni-Cd} & \text{Li-ion} \\ \multicolumn{3}{c}{\begin{bmatrix} 0.3077 & 0.1803 & 0.5385 \\ 0.6154 & 0.5464 & 0.3077 \\ 0.0769 & 0.2732 & 0.1538 \end{bmatrix}} \end{array}$$

Weight Matrix was calculated to be as follows:

$$\begin{bmatrix} 0.3422 \\ 0.4898 \\ 0.1680 \end{bmatrix}$$

Product Matrix of the above was as follows:

$$\begin{bmatrix} 1.0918 \\ 1.510158 \\ 0.498459 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.100417

CI= 0.058696

RI= 0.66

CR= CI/RI = 0.07 (Consistent)

Selection of Batteries according to efficiency

Batteries were prioritized on the basis of efficiency in this calculation.

$$\begin{array}{cc} & \begin{array}{ccc}\text{Lead-Acid} & \text{Ni-Cd} & \text{Li-ion}\end{array} \\ \begin{array}{c}\text{Lead-Acid}\\ \text{Ni-Cd}\\ \text{Li-ion}\end{array} & \begin{bmatrix} 1 & 0.4 & 3 \\ 1.5 & 1 & 2 \\ 0.40 & 0.60 & 1 \end{bmatrix}\end{array}$$

Normalized Matrix was calculated as this.

$$\begin{array}{cc} & \begin{array}{ccc}\text{Lead-Acid} & \text{Ni-Cd} & \text{Li-ion}\end{array} \\ \begin{array}{c}\text{Lead-Acid}\\ \text{Ni-Cd}\\ \text{Li-ion}\end{array} & \begin{bmatrix} 0.3448 & 0.200 & 0.50 \\ 0.5172 & 0.500 & 0.333 \\ 0.1379 & 0.300 & 0.1667 \end{bmatrix}\end{array}$$

Weight Matrix, as derived from the normalized matrix, was found to be this.

$$\begin{bmatrix} 0.3483 \\ 0.4502 \\ 0.2015 \end{bmatrix}$$

Product Matrix was found to be as such:

$$\begin{bmatrix} 1.13295 \\ 1.37567 \\ 0.610958 \end{bmatrix}$$

<u>Consistency Calculation</u>

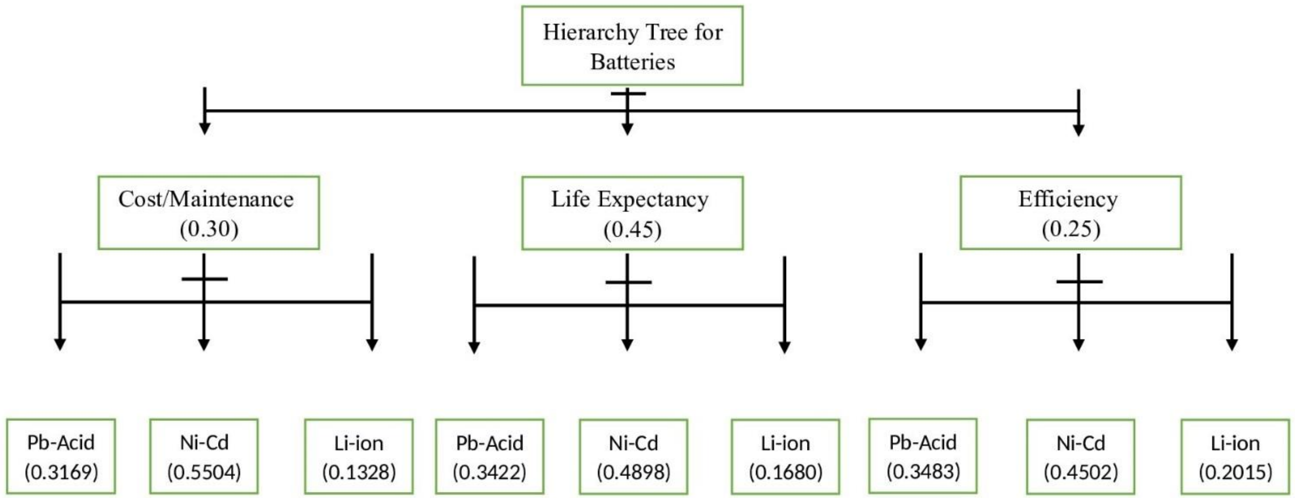
n_{max} = 3.119578

CI= 0.056721

RI= 0.66

CR= CI/RI = 0.10 (Consistent)

The result for the best alternative of batteries to be selected has been specified in Figure 3.



<u>Choice of Lead-Acid Batteries</u>

0.30*0.3169
+ 0.45*0.3422
+ 0.25*0.3483

= 0.336135

<u>Choice of Ni-Cd Batteries</u>

0.30*0.5504
+ 0.45*0.4898
+ 0.25*0.4502

= <u>**0.49808**</u>

<u>Choice of Li-ion Batteries</u>

0.30*0.1328
+ 0.45*0.1680
+ 0.25*0.2015

= 0.165815

Figure 3. The Hierarchy Tree for Batteries

Selection of Grid Technology according to Cost and Maintenance

In the next three calculations, selection of Grid Technology was decided. Three alternatives were prioritized on the basis of three criteria such as cost and maintenance, power and maintenance and efficiency in the end.

$$\begin{array}{c|ccc} & \text{Off-Grid} & \text{Grid-Tied} & \text{Grid-Interactive} \\ \hline \text{OG} & & & \\ \text{GT} & \multicolumn{3}{c}{\begin{bmatrix} 1 & 0.4 & 0.5 \\ 1.5 & 1 & 3 \\ 2 & 0.5 & 1 \end{bmatrix}} \\ \text{GI} & & & \end{array}$$

Normalized Matrix, as calculated from the pairwise comparison matrix was as such:

$$\begin{array}{c|ccc} & \text{Off-Grid} & \text{Grid-Tied} & \text{Grid-Interactive} \\ \hline \text{OG} & & & \\ \text{GT} & \multicolumn{3}{c}{\begin{bmatrix} 0.2222 & 0.2105 & 0.1111 \\ 0.3333 & 0.5263 & 0.6667 \\ 0.4444 & 0.2632 & 0.2222 \end{bmatrix}} \\ \text{GI} & & & \end{array}$$

Weight Matrix was calculated as follows:

$$\begin{bmatrix} 0.1813 \\ 0.5088 \\ 0.3099 \end{bmatrix}$$

Product Matrix was hence calculated as:

$$\begin{bmatrix} 0.539766 \\ 1.710526 \\ 0.926901 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.177193

CI= 0.055009

RI= 0.66

CR= CI/RI = 0.09 (Consistent)

Selection of Grid Technology according to Power Independence

Proceeding from the previous calculation in the similar fashion

$$\begin{array}{c|ccc} & \text{Off-Grid} & \text{Grid-Tied} & \text{Grid-Interactive} \\ \hline \text{OG} & & & \\ \text{GT} & & \left[\begin{matrix} 1 & 0.33 & 0.5 \\ 3 & 1 & 2.5 \\ 2 & 0.5 & 1 \end{matrix}\right] & \\ \text{GI} & & & \end{array}$$

Normalized Matrix was assimilated as follows:

$$\begin{array}{c|ccc} & \text{Off-Grid} & \text{Grid-Tied} & \text{Grid-Interactive} \\ \hline \text{OG} & & & \\ \text{GT} & & \left[\begin{matrix} 0.1667 & 0.1803 & 0.1250 \\ 0.5000 & 0.5464 & 0.6250 \\ 0.3333 & 0.2732 & 0.2500 \end{matrix}\right] & \\ \text{GI} & & & \end{array}$$

Weight Matrix was also calculated in a similar fashion:

$$\begin{bmatrix} 0.1573 \\ 0.5571 \\ 0.2855 \end{bmatrix}$$

Product Matrix as calculated from weight and pairwise comparison matrix multiplied together:

$$\begin{bmatrix} 0.48395 \\ 1.743942 \\ 0.878757 \end{bmatrix}$$

<u>Consistency Calculation</u>

n_{max} = 3.106649

CI= 0.04701

RI= 0.66

CR= CI/RI = 0.08 (Consistent)

Selection of Grid Technology according to Efficiency

In a similar fashion proceeding to get the consistency ratio value for the selection of grid technology, comparing only efficiency we get the following matrix.

$$
\begin{array}{c|ccc}
 & \text{Off-Grid} & \text{Grid-Tied} & \text{Grid-Interactive} \\
\hline
\text{OG} & & & \\
\text{GT} & & \begin{bmatrix} 1 & 0.2 & 0.75 \\ 5 & 1 & 1.5 \\ 2.5 & 0.33 & 1 \end{bmatrix} & \\
\text{GI} & & &
\end{array}
$$

Normalized Matrix for the above pairwise comparison was calculated as follows:

$$
\begin{array}{c|ccc}
 & \text{Off-Grid} & \text{Grid-Tied} & \text{Grid-Interactive} \\
\hline
\text{OG} & & & \\
\text{GT} & & \begin{bmatrix} 0.1176 & 0.1307 & 0.2308 \\ 0.5882 & 0.6536 & 0.4615 \\ 0.2941 & 0.2157 & 0.3077 \end{bmatrix} & \\
\text{GI} & & &
\end{array}
$$

Weight Matrix was found to be as such:

$$\begin{bmatrix} 0.1597 \\ 0.5678 \\ 0.2725 \end{bmatrix}$$

Product Matrix, as derived from the weight matrix, was calculated as follows:

$$\begin{bmatrix} 0.477644 \\ 1.775096 \\ 0.859149 \end{bmatrix}$$

<u>Consistency Calculation</u>

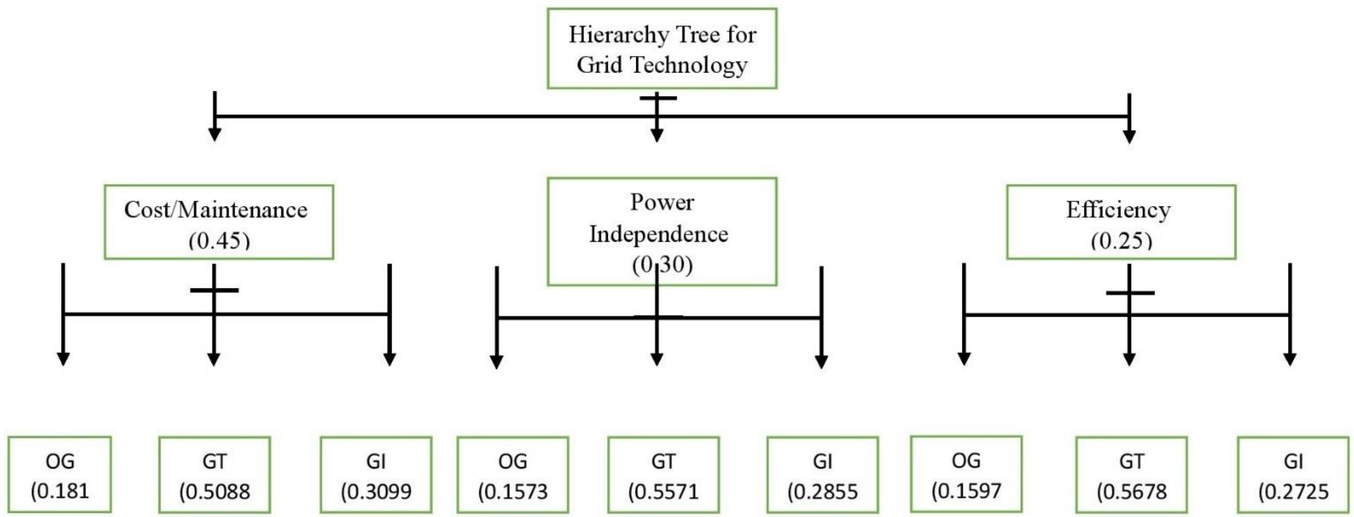
n_{max} = 3.111889

CI= 0.044974

RI= 0.66

CR= CI/RI = 0.08 (Consistent)

The result for the best alternative of Grid Technology has been specified in Figure 4.



<u>Choice of Off-Grid technology</u>

0.45*0.1813
+ 0.30*0.1573
+ 0.25*0.1597

= 0.1687

<u>Choice of Grid-Tied Technology</u>

0.45*0.5088
+ 0.30*0.5571
+ 0.25*0.5678

= **<u>0.53808</u>**

<u>Choice of Grid-Interactive Technology</u>

0.45*0.3099
+ 0.30*0.2855
+ 0.25*0.2725

= 0.2932

Figure 4. Hierarchy Tree for selection of Grid Technology

Selection of Solar Module according to Power-to-Size Ratio

In the next three calculation, decision making for selection of the best solar module is justified. The first matrix is dedicated to the choice of solar module, considering Mono-Crystalline, Poly-Crystalline and Thin Film types upon three criteria; first power-size-ratio, followed by efficiency and life expectancy.

$$\begin{array}{c|ccc} & \text{Mono-crystalline} & \text{Poly-crystalline} & \text{Thin Film} \\ \hline \text{MC} & & & \\ \text{PC} & & & \\ \text{TF} & & & \end{array} \quad \begin{bmatrix} 1 & 0.5 & 0.33 \\ 2 & 1 & 0.75 \\ 3 & 1.5 & 1 \end{bmatrix}$$

Normalized Matrix for the above was calculated as following:

$$\begin{array}{c|ccc} & \text{Mono-crystalline} & \text{Poly-crystalline} & \text{Thin Film} \\ \hline \text{MC} & & & \\ \text{PC} & & & \\ \text{TF} & & & \end{array} \quad \begin{bmatrix} 0.1667 & 0.1667 & 0.1587 \\ 0.3333 & 0.3333 & 0.3606 \\ 0.5000 & 0.5000 & 0.4808 \end{bmatrix}$$

Weight Matrix was calculated as follows:

$$\begin{bmatrix} 0.1640 \\ 0.3424 \\ 0.4936 \end{bmatrix}$$

Product Matrix was found as the following:

$$\begin{bmatrix} 0.498088 \\ 1.040598 \\ 1.499199 \end{bmatrix}$$

<u>Consistency Calculation</u>

n_{max} = 3.037885

CI= 0.018923

RI= 0.66

CR= CI/RI = 0.03 (Consistent)

Selection of Solar Module according to Efficiency

In the following calculation, the best of the three available alternatives for the solar module is calculated on the basis of efficiency.

$$\begin{array}{c|ccc} & \text{Mono-crystalline} & \text{Poly-crystalline} & \text{Thin Film} \\ \hline \text{MC} & \multirow{3}{*}{} \\ \text{PC} \\ \text{TF} \end{array}$$

$$\begin{array}{cc} & \begin{array}{ccc}\text{Mono-crystalline} & \text{Poly-crystalline} & \text{Thin Film}\end{array} \\ \begin{array}{c}\text{MC}\\ \text{PC}\\ \text{TF}\end{array} & \begin{bmatrix} 1 & 0.33 & 0.25 \\ 3 & 1 & 0.75 \\ 5 & 1.5 & 1 \end{bmatrix} \end{array}$$

Normalized Matrix was generated by calculation as follows:

$$\begin{array}{cc} & \begin{array}{ccc}\text{Mono-crystalline} & \text{Poly-crystalline} & \text{Thin Film}\end{array} \\ \begin{array}{c}\text{MC}\\ \text{PC}\\ \text{TF}\end{array} & \begin{bmatrix} 0.1111 & 0.1166 & 0.1250 \\ 0.3333 & 0.3534 & 0.3750 \\ 0.5556 & 0.5300 & 0.5000 \end{bmatrix} \end{array}$$

Weight Matrix was found as such:

$$\begin{bmatrix} 0.1176 \\ 0.3539 \\ 0.5285 \end{bmatrix}$$

Product Matrix, obtained after multiplication of weight matrix and pairwise comparison matrix was as follows:

$$\begin{bmatrix} 0.366491 \\ 1.103013 \\ 1.647240 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.116744

CI= 0.058425

RI= 0.66

CR= CI/RI = 0.10 (Consistent)

Selection of Solar Module according to Life Expectancy

The following calculation is the last leg of the three set calculation for selection of the solar module. This matrix was calculated taking into consideration only the life expectancy of the solar module alternatives available to us: Mono-Crystalline, Poly-Crystalline and Thin-Film type.

$$\begin{array}{c|ccc} & \text{Mono-crystalline} & \text{Poly-crystalline} & \text{Thin Film} \\ \hline \text{MC} & & & \\ \text{PC} & & & \\ \text{TF} & & & \end{array} \quad \begin{bmatrix} 1 & 0.33 & 0.67 \\ 5 & 1 & 0.25 \\ 2 & 0.50 & 1 \end{bmatrix}$$

Normalized Matrix was calculated as follows:

$$\begin{array}{c|ccc} & \text{Mono-crystalline} & \text{Ploy- crystalline} & \text{Thin Film} \\ \hline \text{MC} & & & \\ \text{PC} & & & \\ \text{TF} & & & \end{array} \quad \begin{bmatrix} 0.1250 & 0.1803 & 0.34990 \\ 0.6250 & 0.5464 & 0.1302 \\ 0.2500 & 0.2732 & 0.5208 \end{bmatrix}$$

Weight Matrix was thus calculated as the following:

$$\begin{bmatrix} 0.2181 \\ 0.4339 \\ 0.3480 \end{bmatrix}$$

Product Matrix obtained after multiplying pairwise comparison and the weight matrix was found as follows:

$$\begin{bmatrix} 0.594450 \\ 1.611367 \\ 1.001153 \end{bmatrix}$$

<u>Consistency Calculation</u>

n_{max} = 3.20697

CI= 0.052695

RI= 0.66

CR= CI/RI = 0.09 (Consistent)

Selection of plant location according to available gridding space

One of the most important selection made was the choice of the location the plant should be set up, considering mostly just one criterion that is the space available for gridding.

Main Building North Block	LA 1 + BM/BT	Cluster of hostels

$$\begin{array}{c} \text{MB} \\ \text{LA} \\ \text{Hostels} \end{array} \begin{bmatrix} 1 & 0.25 & 0.60 \\ 1.5 & 1 & 0.75 \\ 5 & 7.5 & 1 \end{bmatrix}$$

Normalized Matrix was thus calculated as this:

Main Building North Block	LA 1 + BM/BT	Cluster of hostels

$$\begin{array}{c} \text{MB} \\ \text{LA} \\ \text{Hostels} \end{array} \begin{bmatrix} 0.1333 & 0.1250 & 0.2533 \\ 0.2000 & 0.5000 & 0.3191 \\ 0.6667 & 0.3750 & 0.4255 \end{bmatrix}$$

Weight Matrix was thus calculated as:

$$\begin{bmatrix} 0.1712 \\ 0.3397 \\ 0.4891 \end{bmatrix}$$

Product Matrix

$$\begin{bmatrix} 0.549586 \\ 0.963342 \\ 1.599941 \end{bmatrix}$$

<u>Consistency Calculation</u>

n_{max} = 3.112869

CI= 0.052836

RI= 0.66

CR = CI/RI = 0.09 (Consistent)

Most suitable location thus found was the "Hostel Top", connected through the Grid-Interactive system.

Selection of Grid size according to Cost and Maintenance

The last phase of decision-making depended on the choice of Grid size. This was done primarily on the basis of three criteria: cost and maintenance first and then the usable energy produced, and daily campus requirement respectively. Considering only cost and maintenance, one of the three choices had to be chosen: 1 MW, 1.5 MW and 2 MW.

$$\begin{array}{c|c} & \begin{matrix} \text{1 MW} & \text{1.5 MW} & \text{2 MW} \end{matrix} \\ \begin{matrix} \text{1 MW} \\ \text{1.5 MW} \\ \text{2 MW} \end{matrix} & \begin{bmatrix} 1 & 3/4 & 3/5 \\ 4/3 & 1 & 4/5 \\ 5/3 & 3/2 & 1 \end{bmatrix} \end{array}$$

Normalized Matrix from the pairwise comparison matrix:

$$\begin{array}{c|c} & \begin{matrix} \text{1 MW} & \text{1.5 MW} & \text{2 MW} \end{matrix} \\ \begin{matrix} \text{1 MW} \\ \text{1.5 MW} \\ \text{2 MW} \end{matrix} & \begin{bmatrix} 0.2500 & 0.2308 & 0.2500 \\ 0.3333 & 0.3077 & 0.3333 \\ 0.4167 & 0.4615 & 0.4167 \end{bmatrix} \end{array}$$

Weight Matrix thus obtained by row averaging the normalized matrix was as follows:

$$\begin{bmatrix} 0.2436 \\ 0.3248 \\ 0.4316 \end{bmatrix}$$

Product Matrix as calculated from the weight matrix

$$\begin{bmatrix} 0.746154 \\ 0.994872 \\ 1.324786 \end{bmatrix}$$

<u>Consistency Calculation</u>

n_{max} = 3.065812

CI= 0.032604

RI= 0.66

CR= CI/RI = 0.06 (Consistent)

Thus the best alternative was 2 MW, as far as only cost and maintenance is concerned.

Selection of Grid Size according to usable energy produced

Proceeding in the similar manner, the three alternatives were weighed on the basis of daily usable energy produced. The pairwise comparison matrix would be as follows:

$$\begin{array}{c|ccc} & 1\text{ MW} & 1.5\text{ MW} & 2\text{ MW} \\ \hline 1\text{ MW} & & & \\ 1.5\text{ MW} & & \left[\begin{matrix} 1 & 2/3 & 1/2 \\ 3/2 & 1 & 4/3 \\ 2 & 3/4 & 1 \end{matrix}\right] & \\ 2\text{ MW} & & & \end{array}$$

Normalized Matrix was thus computed from the pairwise comparison by taking the proportions of the matrix elements from column averages:

$$\begin{array}{c|ccc} & 1\text{ MW} & 1.5\text{ MW} & 2\text{ MW} \\ \hline 1\text{ MW} & & & \\ 1.5\text{ MW} & & \left[\begin{matrix} 0.2222 & 0.2739 & 0.1767 \\ 0.3333 & 0.4149 & 0.4700 \\ 0.4444 & 0.3112 & 0.3534 \end{matrix}\right] & \\ 2\text{ MW} & & & \end{array}$$

Weight Matrix, as calculated from the normalized matrix, was as follows:

$$\begin{bmatrix} 0.2243 \\ 0.4061 \\ 0.3697 \end{bmatrix}$$

Product Matrix obtained from the multiplication of weight matrix and pairwise comparison matrix was as follows:

$$\begin{bmatrix} 0.6770999 \\ 1.234117 \\ 1.122734 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.0339509

CI= 0.015933

RI= 0.66

CR= CI/RI = 0.03 (Consistent)

Thus, 2 MW choice was prior to the two others if only daily available energy is concerned.

Selection of Grid Size according to Daily Campus Requirement

Considering the daily campus requirement only, the following calculations were made. The requisite pairwise comparison matrix was as follows:

$$\begin{array}{c|c} & \begin{array}{ccc} \text{1 MW} & \text{1.5 MW} & \text{2 MW} \end{array} \\ \begin{array}{c} \text{1 MW} \\ \text{1.5 MW} \\ \text{2 MW} \end{array} & \begin{bmatrix} 1 & 0.33 & 0.20 \\ 3 & 1 & 1.67 \\ 5 & 0.60 & 1 \end{bmatrix} \end{array}$$

Normalized Matrix, as calculated by diving the above matrix by the respective column averages, was as follows:

$$\begin{array}{c|c} & \begin{array}{ccc} \text{1 MW} & \text{1.5 MW} & \text{2 MW} \end{array} \\ \begin{array}{c} \text{1 MW} \\ \text{1.5 MW} \\ \text{2 MW} \end{array} & \begin{bmatrix} 0.1111 & 0.1710 & 0.0699 \\ 0.3333 & 0.5181 & 0.5804 \\ 0.5555 & 0.3109 & 0.3497 \end{bmatrix} \end{array}$$

Weight Matrix obtained from the row averages of the above was as such:

$$\begin{bmatrix} 0.1173 \\ 0.4773 \\ 0.4054 \end{bmatrix}$$

Product Matrix obtained after multiplying the weight matrix and the pairwise comparison matrix was as follows:

$$\begin{bmatrix} 0.355922 \\ 1.278449 \\ 1.502223 \end{bmatrix}$$

Consistency Calculation

n_{max} = 3.136594

CI= 0.055735

RI= 0.66

CR= CI/RI = 0.10 (Consistent)

Thus after considering all three alternatives against all three criteria, 2 MW grid size was calculated to be the most suitable and necessary for the proposed plant.

Chapter 5.

Result & Discussion

The choices of the best-suited alternatives for the proposed solar power plant were decided neatly by AHP method. By AHP method, using the relative common attributes and thus making the pairwise comparison, the most effective alternatives were chosen. The chosen alternatives via AHP method clearly satisfy the objectives of maximum efficiency, maximum power independence, least cost and maintenance expenses, life expectancy etc. It was made sure that, the options chosen are close to the reference and do not much deviate from the ideal threshold of the acceptable values in all the cases considered. It was done by adjusting the comparison matrices so as to achieve a consistency ratio less than or equal to 0.01. In all the individual comparisons, Consistency Index (CI), Random Inconsistency (RI) were calculated so as to find the Consistency Ratio (CR) value accordingly. The detail results and observations concluded of the AHP method for the setting up of the solar power plant in the campus, are given in Table 4.

Table 4. Final result for the selection of best alternative

Sl. No.	Choice of the Plant Constituent	Most Important Criterion	Best Alternative
1	Inverters	Efficiency	Small Scale Solar Arrays (SSS)
2	Batteries	Life Expectancy	Ni-Cd Batteries
3	Grid Technology	Cost	Grid-Tied Service
4	Solar Module	Conversion Efficiency	Poly-Crystalline Solar Modules
5	Choice of Location	Available Gridding Space	Cluster Gridding above the Hostels
6	Choice of Grid Size	Usable Energy produced/day	2 MW

Chapter 6.

Conclusion

Selecting the best from different Renewable Energy project activities obliges that distinctive gatherings of decision advisers get indulged in the entire process. The obvious and prominent fact here in NIT Rourkela is that due consideration of social, financial, technological as well as, natural elements are taken in decision-making which would make the process more complex. These had to be considered along with the life expectancy and feasibility of the project. Conventional single-standard decision-making is no more ready to handle these issues appropriately. The approach plan for fossil powers energy substitution by Non-conventional Energies must be tended to in a multi-criteria connection. In this paper, it has been tried to indicate how the AHP strategy, can be effectively used while taking important decisions of selecting alternatives in establishing a campus-based solar power plant. The applied methodology has been intricately evolved throughout the process starting from the selection of most important criteria to choosing the best available alternative. In this project work, the AHP based ranking of various constituents of the proposed solar power plant to be based in NIT Rourkela, have been compiled. This certain approach towards solving the decision-making problems gives the authorities, one of the best possible set of alternatives for choice of inverters and batteries etc. after making a thorough criterion based comparison. The purpose of taking up this project is hence satisfied as the solution is expected to reduce the cost of the solar project as well as maximize its life expectancy.

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